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Damming the river: a changing perspective on altering nature

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Abstract

Dams have served society for over 4500 years. Through time, functions and uses have been notably altered. There has been a significant proliferation in purposes for constructing dams to control stream flow and secure water storage. Technological changes have been paralleled with construction of ever-larger dams to gain control of larger water supplies. This study of dams is presented in the context of environment and societal needs. Dams act as geomorphic agents as well as water management structures. It is essential to anticipate a barrier's long-term environmental influence as well as to measure its long-term role in serving society. The analysis considers the varied magnitudes of dams and their respective functions to serve ever-larger populations. Dam size is a reflection of the changing dependence of society on specific water functions/services. As nature has its rhythm of change, the challenge is to fit human use into nature with minimal adverse environmental impacts. As with agriculture, dams have become part of the domesticated landscape.

Keywords: Dams; Hydroelectricity; Environmental change; Conservation; Domesticated landscapes

Contents

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1. Introduction

Damming rivers has a history that extends over 4500 years into the past. In antiquity, water management by individuals was too large and too remote to be part of thoughts and actions. Ideas of water management arose among people subsequent to the agricultural revolution and the inception of urbanization (Bairoch, CITIES, 1988, 8–15). Need and a measure of water security provided the early impulse to control water storage in streams with the construction of barriers. Earliest water barriers in streams and rivers served water storage in arid lands for irrigation and urban water needs. The idea for water management of rivers arose foremost in arid realms where organized societies sought roots in irrigation agriculture and compact urban places (Mesopotamia & the Indus valley) may serve as examples, see also [1], p. 520–557, especially pages 520–1, 528–530 and [2], p. 50–9. Organization of essential water management to secure crop growth and production 8500–6000 years ago is in part conjectural and shaped by 21st century environmental management precepts. One has to allow for isolated cases of water management for crop production and human needs, but also for larger population clusters such as suggested by Wittfogel [2], where water was authoritatively controlled. This fosters the assumption of the formation of a technical collectivity guided by political decision makers to meet specific

social regional water needs [2]. By the time that hydraulic societies formed, a certain body of collective experiences possibly provided model and incentive for government authorities to impose their will upon a water management system. Of significance here is that such systems possibly came into existence to regulate a limited resource-water for a rural and urban society. At the same time the Sadd el-Kafara dam (2950–2750 BC) in the Nile Valley illustrates the early efforts to regulate stream flow with the installation of a major barrier, [3]. From those beginnings to the present time, population numbers have grown at an accelerating rate, and technology has been changing with increasing specialization, responding to shifting levels in resource demand and use. In the past nature proved more difficult to modify for reasons of limitations in available tools and technology. The pace of environmental transformation reflected the level of technical means available then. Advances in technology continuously reduced this constraint with the consequence that ever more massive projects were implanted in river valleys, significantly changing nature. The process is not one of deliberate mutilation of natural systems; it constitutes societal responses to growth in numbers and intensified uses of the resource base.

2. Purpose of study

Water is a multi-faceted resource commanding universal attention and fostering structured management systems. The focus of this study is upon water usage for electricity generation.[1] To this end dams are built, which turn into river barriers. The impounded

[1] Multiple dams generally are favored over single function entities. Multi-purpose dams eventually in their operation identify the proportionality of function and resource utilization. In ‘A River Diverted, the Sea Rushes In,’ Eckholm provides measured insight on water uses in the Indus valley system, Pakistan. Irrigation for agricultural land uses is generally assessed with 70% of all water uses worldwide. If evaporation of water from the open water body-reservoir is added, another 8–10% may have to be added, dependent on latitude and location. Then too, the amount of water lost to seepage from irrigation canals and ditches is another loss that has to be accounted for. The sum of water loss to irrigation, and if multi-annual cropping is the norm, explains in part why the Indus River waters no longer reach the Arabian Sea in adequate mass to keep the waters of the Arabian Sea from moving the Indus River upstream and salinize the downstream floodplain. In the process the local ecology is changed and extensive tracts of agricultural lands are lost to production [12] p. 4. Hydroelectric entities create an up- and down-stream system. Reservoirs lose water to evaporation. Water used for power generation is unaltered, a pass-through process with actual minimal water loss. Hydroelectric projects alter the river regime, but are the cause for minimal water losses. It is desirable to identify specific water uses, functions, and depletion of water supplies, to allocate functional and economic weights in realistic terms. The experience repeated for the Indus River, has been repeated for the Yellow River, China [35] and this too is the result of excessive water withdrawals for cropland irrigation, not power generation. And here too the Yellow Sea is moving upstream in the Yellow River. The Chinese aim to correct this with linking the Yangtsee by means of feeder canals with the Yellow River, to achieve balanced river regimes. This constitutes an enormous engineering enterprise. To balance water needs under the demographic weights of China and India constitutes a challenge of inexperienced dimensions. In this context, the Indian government recently divulged a general plan to integrate the Indian river system to achieve more effective water management nationwide and greater balance in water availability throughout (Luce, ‘India,’ FINANCIAL, 2003 [36]). Possibly one of the most notable water withdrawals with celebrated consequences is the case of the Syr Darja River and the Aral Sea. Diversion of the Syr Darja River’s waters into irrigation agriculture, especially cotton and other field crops resulted in rapidly advancing desiccation of the Aral Sea. The initial phase dates to 1961, by 1990 only 6 km^3/year of water reached the lake, which averaged 55.3 km^3/year for the 1927–1960 period [10]. Irrigation project dams maybe lower barriers than these observed for hydroelectric projects, their purpose and function departs radically from the former which in effect are active water consumers.

mass of water behind such dams comes to rest in reservoirs that vary in magnitude, not necessarily proportional to dam size or amount of power generated. Attention is directed toward project infrastructures that harness the moving water in its passage through the turbine to generate electricity. Dams can be considered a mirror of the technology furthered by energy-dependent social systems. Coincident with emphasis upon electricity generation is a detailed analysis of the environmental alterations that dams produce in river systems. Dam construction is a response by select societies to meet their increasing electricity needs.[2] Dams create social relocation needs, but also how do they service ever larger and more complex urban industrial systems? Growing population numbers, longer life spans, higher standards of life contribute significantly to put additional pressure upon social infrastructure and its encroachment upon the physical resource base. It is at this junction that the ideal and the real have to find common ground to achieve effective coexistence. Conservation is possibly the most effective means to reduce pressure upon the physical environment. Second, technology is another indirect instrument of conservation of resources when it can be made instrumental in reducing energy and water demand. This is by means of more energy efficient machinery and by more effective water uses in irrigation agriculture. For this brand of conservation economic benefits must exceed application costs.

3. Society, technology and unanticipated changes

Individuals generally make minimal imprints upon the physical environment. It is as collectives, as a society, that imprints upon the land take on varied dimensions as a consequence of collective decisions and actions. From crop domestication to animal domestication, culminating in urban place formation, that the more pronounced environmental alterations emerge out of concerted social actions. The first dams were an effort to control stream flows for agriculture and urban water supply. The onset of the industrial machinery with the aid of waterwheels was set in controlled raceways. Advances in urbanization added the urban water supply requirements, which in many instances led to weir building, or low level dams. Change in technology led to changes in dam construction and water uses. Concurrent with these changes came the invention of electricity by Faraday (1791–1867) and the Francis Turbine by James B. Francis (1815–1892). Edison invented the light bulb, the first thermal station, and the move from oil and gas lamp to electric lamps was at hand. Night was turned into day, and convenience replaced the cumbersome isolated energy source of individual lamps. The ramifications of the changes ahead were similar in magnitude to those created by Gutenberg with the printing press. Whether Edison had any idea about computers or Bell any notion of fiberglass is at best speculative, but their inventions provide bases for far reaching changes. Nor were these creative individuals aware of the changes they were about to

[2] Wittfogel addresses governmental water control as authoritarian in application. It is doubtful that this was a universal practice; hence it is appropriate to allow for variation in water management practices and systems. The early approaches to water management may be difficult to reconstruct, but further study encourages active research and eschews reductionism.

introduce in the spatial order of culture, economy, and policy. Dams for hydropower are then an invention for which neither number nor magnitude entered the concerns of their originators. In essence, the changes recorded mirror the changing perceptions of policy planners, who in turn were guided by the demographic, economic, and social changes that furthered rising standards of living, and with it demand for energy. At the time, most were driven by optimism, and one can assume they were at best passively aware of Marsh's The Earth as modified by Human Action [32], and unfamiliar with the environmental consequences of their decisions. Precedents were inadequate to point to the potential impacts of their actions. Hence, the issues addressed here evolve over centuries, and their resolution is expected in a 'Polaroid' moment—nearly instantaneously. That changes were imperative hardly needs to be stated, how to achieve them was and continues to be the challenge.

Most changes caused by inventions produce desirable results or so it seems. Only over the longer term are the shortcomings and hazards revealing themselves with the prolonged usage of such inventions [4]. Whether one considers saccharine, cigarettes, DDT, PCB, or antibiotics, all served a particular need for a time. However, eventually unexpected effects emerged that showed that their harm exceeded their benefits, and their usage has subsequently been constrained as consequence of public policy changes. Dams were built to serve as 'white coal' for those without adequate domestic energy alternatives, notably in Norway, Switzerland and Italy. In the US, the TVA was created to serve multi-purpose functions. Each hydro project is a specific response to a particular energy scenario. Hydro project planning initially was environmentally aware rather than comprehensive in scope. Numerous hydro projects were planned and built to serve specific interests without a long-term view of project social and environmental impacts. Numerous projects built in foreign lands were technically feasible, but socially, economically and environmentally out of place [5]. Moreover, project specific shortcomings can be identified [6,25]. That approach neglects to address the multiple land use transformations throughout, in which agriculture dominates the world scene. Merely consider the devastation of the natural landscape that agriculture introduced in the US farm belt without giving any thought here to the Central Valley of California [7], p. 350–366. Dams bring unintended changes to the environment. Much of the change depends upon project size and location impacting local geomorphology. In the past foremost concern was fault stability and sediment loads. Vegetation and fauna are more recent variables of attention. Resettlement and disease vectors (Careless technology) were other reasons for concern that served to instigate criticisms against dams while vegetation and fauna received less immediate attention. By now there is an IRN (International Rivers Network), which has become a major NGO to protest virtually all dams. Gleick has weighed in with dam removals in his latest bi-annual reports [26,27]. As project magnitude increases, especially reservoir area and water volume, the environmental parameters can be modeled, but the real impact emerges more accurately some 10 years after full river closure. Any analysis of dams and the consequences they cause environmentally has to be balanced in terms of functions. The role of navigation, flood control, water supply regulation, fish production, recreation, irrigation, energy production, sedimentation, limnology, all of these call for planning analysis as well as project analysis. ICOLD (International Committee of Large Dams) has turned its attention to the need for pre-project analysis and review of key projects on line. [8].

4. Dams and environment

4.1. Dams in general

Most any barrier across a stream or river that is durable and serves to store water for future uses is a dam. In antiquity dams were placed across rivers to serve the specific water needs of urban and rural communities. As such, dams served as instruments of water management and provided a level of water security that was indispensable for the functional existence of urban places and agricultural settlements. Initially, dams were relatively small projects. Water storage dams were modest in dimension and their locational effect applied to the immediate area of siting. Dam characteristics and locations changed with advances in technology and materials used in construction.

4.2. Dams and hydroelectric generation

Dam functions and their magnitude changed at an accelerating pace once the first hydroelectric dam entered service at Appleton, WI in 1882. As hydroelectric projects gained growing acceptance as electricity generators and as transmission technology improved, their size sustained notable growth. Early dams had a modest kiloWatts potential, ranging from 500 to 10,000 kW, often measured in hp (horsepower; 1 hp = .73 kW). At that level there is environmental impact, but in significance these are modest when compared to project magnitudes of 500,000 kW and larger. Passage of time has metamorphosed micro into macro projects such as Grand Coulee, Hoover, Itaipu, Guri or Three Gorges. This lateral perspective (Fig. 1) provides a visual measure for an 8300 MW unit as implanted in a river valley. Dam size increases have been accompanied in most cases with proliferation of multiple functions, such as irrigation, urban water supply, energy, flood control, navigation, recreation and fishing as the more widespread uses. The idea of the dam has sustained notable changes and varied metamorphoses. It is hydroelectric dams that gradually attracted most of the negative attention, partly the result of their size impacting upon riverine settlements that were forced to relocate. Moreover, the electricity was consumed in distant population poles without contributing to the standard of life whence the electricity originated. Key objections centered on forced human resettlement, which must be seen as traumatic for indigenous peoples [9] as well as for old settlements as noted in China and India. Without barriers to the reservoir areas, dams could readily serve as disease incubators in settings where local cultures were not prepared for the coming changes in their lives. In the urgent need for additional energy sources, inclusion of prophylactic health measures in the dam planning process became notable for their absence as well as the absence of settlement constraints in the reservoir areas. If human needs drew initial attention, the need for environmental evaluations gained in significance dating to the early 1970s. And it is these variables that have to be addressed. While only hydroelectric dams are here considered, in the US they comprise 2.8% of all dams. Even in water volume stored, hydroelectric dams account for only 9.8% of all stored water behind dams in the US. Hydroelectric dams are thus completely overshadowed by the sum of all other dams in the US [10], p. 366. Hydroelectric projects vary in size and projected functions. Such projects come into existence in response to identified

Fig. 1. Tucurui dam on the Tocantins River, in July 1984, a lateral perspective looking south (upstream). Below the spillway shallow rapids are visible. Above the dam large outcrops point to the boundary zone of the Brazilian shield. This segment of the river was never navigable, which led to the construction of the Tucurui–Jatobal railroad, to service as export instrument for the region's Brazil nut production. The escape canal (right side in photo) for the powerhouse in July was in the process of being cleared of all excessive base rock for November entering service. Note the elevational difference between the water level in the spillway canal and the significant deeper escape canal of the powerhouse on the right.

socio-economic needs. Multi-functional projects may include navigation, irrigation, flood control, ichtyofauna, urban water supply, recreational functions, and energy generation. Furthermore, it should be noted how difficult it becomes to protect nature and service society creatively. Nor should the 'invisible hand' of urbanization be considered lightly when assessing 'dam impact' upon river systems and the environment.

Among the many possible considerations, the following guide a good part of this analysis:

1. Dams across rivers—changing nature;
2. Water management without dams on land to date is difficult, if not impossible;
3. Dams belong in the public domain to prevent socially detrimental economic or political water manipulation;
4. Dams should include locks on navigable rivers and sluices under the spillway to facilitate release of sediment accumulation during the high stream flow period.

4.2.1. Dams across rivers: changes in river geomorphology

Dams introduce a break in the natural discharge regime of rivers (Fig. 1). This brings into existence an up-dam geomorphology and a down-dam geomorphology. In the up-dam segment the more conspicuous change will be noted at the upper segment of the reservoir,

where sedimentation will be most massive. Any tributaries to the main river a short distance from the reservoir's upper entrance tend to develop delta systems in response to the break in water velocity and sediment deposition. This brings with it changed habitats for flora and fauna. Another feature to be considered in the environmental context is the number of bays and islands that form in the reservoir area. Many of these bays turn into isolated storage segments from which water will move if at all, slowly and only with reservoir level variation, it will rather remain generally inactive, essentially stagnant in the river system. These marginal pools of stagnant water often become covered with aquatic vegetation, which tends to be prolific in tropical environments. This stationary water influences water characteristics, especially during the first years of dam closure. These conditions are further influenced by stream volume and renewal of the water body. The more massive the stream flow, the more frequent the water renewal of the stored water. Water renewal is not universal because spillway and water intake tends to be significantly above original stream level. This introduces the hypolimnion, which is dead water storage, as there is no way to change it unless sluices are part of the spillway structure. This, in turn, creates water stratification that varies with volume and season. Petts identifies three key strata: (1) the epilimnion, the upper strata; the most active layer, (2) the metalimnion, the middle strata which changes with variations in reservoir levels, and (3) the hypolimnion, the lowest strata which tends to fossilize because of its general immobility [11], p. 54–87. Sluices are operated below the spillway; these are not common because of high costs and delayed uses. These would make possible the change of the different water layers in the reservoir.

Reservoir size has to be considered in vertical and horizontal dimension in relation to total annual stream flow to measure the environmental impact of the dam. The greater volume of water carried spells more frequent renewal of reservoir water, or the period of residence varies directly with stream flow. Pangue Dam (Bio Bio, Chile), with about 540 ha in reservoir area, is nearly a run-of-the-river dam, Tucurui with about 248,000 ha, and 52.8 km^3 of water, a major river, has about 47 days of residency, or its average annual water renewal of the stored water is 7.76 times. A more accurate picture would be if the water is divided into three layers, and exclude the hypolimnion, the lowest, then renewal of the active water is more frequent than the 7.76 times indicated.

The down stream river is a regulated river for the greater part of the year. First, it means floods have been eliminated as an annual event. Once a 100- or 1000-year flood may happen, but here spillway magnitude becomes critical. For much of the year water at Tucurui for the most part passes through the turbines, significantly reducing the river's downstream function as a geomorphic agent. River scour is greatly altered and sediment barriers may form that turn into islands and channel blockers. Alluvial deposition will be minimal and floodplain soil profiles tend to change into fixed strata as the sedimentation process has been modified. The impact upon floodplain agriculture varies with region, but dams have a role in this change as well.

4.2.2. Dams and water management

Dams serve a multitude of water uses. Population increases and changing economic priorities induce ever more water management schemes. As competition for water uses intensifies and more rational schemes become necessary, environmental alterations

gain in scale. Dams serving as hydroelectric stations change in scale as transmission distances decrease as a constraint and as demand for electricity increases relentlessly. These conditions and processes repeat themselves throughout much of the world where hydropower can serve as major local energy source. Moreover, there are pressures to design or construct dams that will serve both, the needs of irrigation and energy production. In the Nile Valley urban water uses are significant and the same is true of the Indus River. This presents the question, which water use influences project magnitude and the time frame for its construction. How will the formation of water use be allocated? In the Indus valley water use is allocated in large part to irrigation [12], in the Nile Valley it serves foremost energy generation, and second urban water systems, as well as irrigation. In the Nile-the Aswan Dam height and reservoir volume have their respective costs in civil infrastructure of the dam and the area needed for the reservoir.

In tropical regions project planners need to include evaporation rates and mass of water losses (in the Aswan area about 440 m^3/s and in the Sao Francisco-Sobradinho Dam about 210 m^3/s are lost to evaporation). Another possible water loss behind a dam is lateral drainage via faults, rock fissures or sinkholes. These conditions are cited, though these may apply to select instances only. Possibly one of the starkest water management problems has been associated with the Amu Dar'ya and Syr Dar'ya Rivers, key affluents to the Aral Sea. River barriers present many opportunities, but a corresponding number of problems [10], p. 5. Hydropower, over the long-term causes fewer challenges and dislocations than other uses because it is not really a water use, in that no water is removed from the river system, but instead its flow is regulated. Hydroelectric dam planners and managers observe water availability most intently to achieve maximum project viability. Water management in general has achieved a status that it never enjoyed in economics courses of the past when water was described as a 'ubiquitous' resource. Water is no longer a 'ubiquitous' resource, nor can it be effectively managed without some structure to regulate its free flow and perhaps some user fee.

Water passing through hydroelectric structures can be divided into three categories, namely that needed to turn the turbine, the excess water that has to be released through spillway gates or sluices, and third the water lost to evaporation. Each of these segments varies with the rainfall regime in each particular watershed and particular season. The amount of water needed to power the turbines is set by water availability and electricity demand. This is the amount of water that the turbine requires to operate at 85% of installed capacity to provide the required base load. Dam managers observe stream flow to maintain optimum reservoir levels, anticipating precipitation variations. These calculations enter the projections of electricity demand for a 'normal' operational year. The greater the number of dams on the same river, the more water regulation is available, increasing the % productive effectiveness of each succeeding dam. At Tucurui dam on the Tocantins River, Para, Brazil, one turbine needs 584 m^3/s, then 23 units, if all are on line and of the same size, will pass 13,432 m^3/s, while the Tocantins' annual mean flow is 11,200 m^3/s. The 2432 m^3/s deficit illustrates the need for a massive reservoir and reliable rainfall.

Excess water has to be released via the spillway. The peak volume is unpredictable in quantity and exact time of passage. The greater the volume, the more the dam resembles a waterfall, 40,000 m^3/s are a common peak value for Tucurui, or nearly 27,000 m^3/s have

to pass the spillway besides 13,432 m^3/s passing the turbines. Should the river reach 50,000 or 60,000 m^3/s the amount of unused water temporarily changes the fluvial regime.

Evaporation losses have to be included in any assessment of water management in hydroelectric systems. Loss to evaporation varies with latitude and reservoir size. In many cases this tends to be a minor factor, but in the tropics, especially in the semi-arid to desert conditions, which can be termed, the river in the air or evaporation, has to be included in project planning. The Aswan High Dam, Egypt, and Sobradinho, Brazil, serve as conspicuous examples for sizable water losses. While the emphasis is on hydroelectric dams, the reader is invited to reflect upon the water losses from more shallow reservoirs that serve irrigation requirements and urban water needs. The use of liquid film to reduce evaporation sounds plausible, but the viscosity of the chemicals generally fragments under the impact of wind and wave.

4.2.3. *Dam size in the context of changing nature*

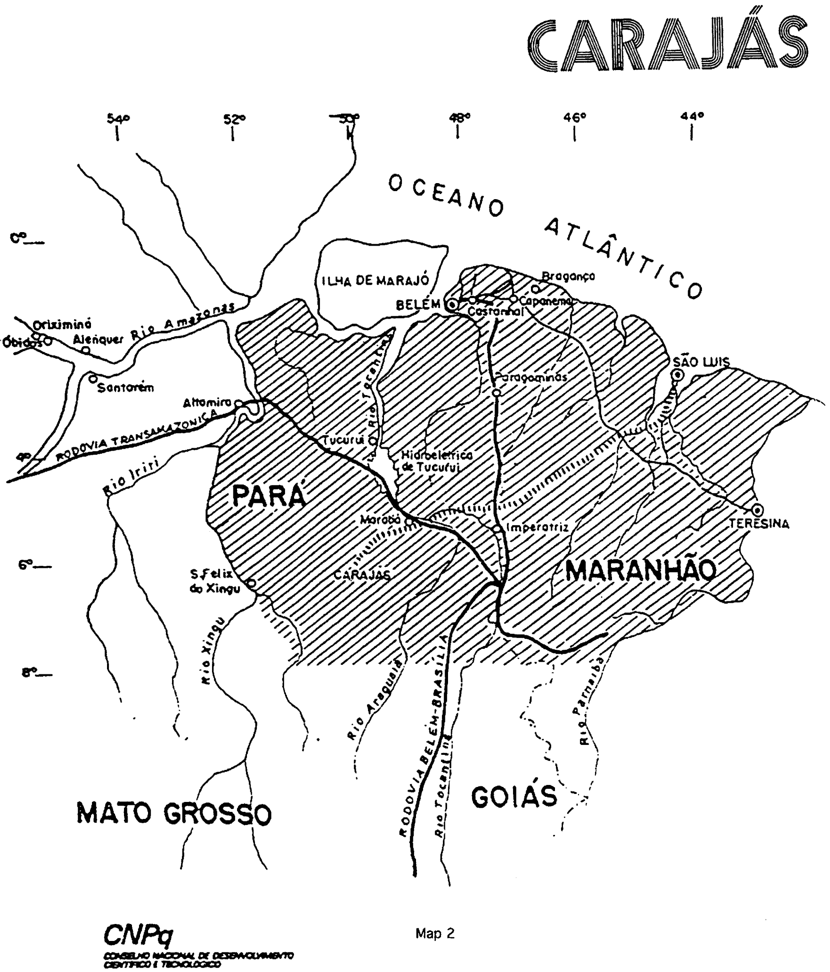
Society and water management have a considerable history to influence thinking and action on how to control and use this resource[2] [2,10]. Contemporary water needs and large hydroelectric plants have to be placed into a national system context. The bulk of energy is destined for places distant from the place of generation. Inter-agency planning then serves to create effective linkage between producer and consumer. Electricity consumption fluctuates with the economic rhythm, water availability cannot be taken for granted, though river regimes vary from year-to-year, and they have seasonal patterns. The earth has a water budget to which social systems have to conform. The amount of precipitation that falls annually on land is an estimated 119,000 km^3, of which 61% is returned into the atmosphere, or leaving 47,000 km^3 for land and people. [13], p. 15.

At this juncture the analysis focuses on the Brazilian setting. The local context affords perspective including attention to socio-environmental tensions that accompany dam-construction and dependence. Moreover, it is river basins and their respective magnitudes that set the parameters to water uses and their manipulation by societies. At this juncture the notion to harness any segment of the Amazon is out of the question environmentally, economically and technically. It is its tributary system that attracts the attention of hydroelectric planners to the Amazon region. The Tocantins River (Map 1c), a tributary to the Para River, has attracted the most attention for energy use in the Amazon basin as it is closest in distance to large population centers, and thereby reduces electricity transmission distances and infrastructure investment requirements. The planning and placement of Tucurui dam provides insight into resource planning, energy policy, and regional politics.

Tucurui dam is considered in more detail to illustrate its function in the resource mobilization of Eastern Amazonia (Map 1a–c). Tucurui serves as a key to open numerous doors to the inclusion, integration, of Eastern Amazonia into the Brazilian Economic system. The planning was carried out in Brasilia, influenced indirectly by 'Paulista interests' (Sao Paulo state), without much of any contribution from the people of Para state, where the dam is located. Large iron ore and bauxite deposits had been identified in Para state in the late 1960s and early 1970s, followed by regional energy studies (Map 2). With the military in power, integrated development planning gained a following. The 1973 energy crisis put Brazil's economy into a severe squeeze. Energy project planning when no ostensible fossil fuel resources had been identified moved major domestic hydroelectric

Map 1. [39]

energy projects upon the priority list. Tucurui became one such project, sitting astride the Tocantins, occupying a central location 300 km south of Belem and about 270 km to the northwest of the Carajas iron ore deposits. Tucurui is about 150 km west of the Paragominas bauxite deposits, a reserve of 2.4×10^9 tons and roughly 650 km southwest of Sao Luis, another major aluminum producing center. This was an unusual linkage of long-term strategic economic planning.



Map 2. [38]

The energy policy in the 1970s became one to use the hydroelectric potential of the state and region. Tucurui occupied a prominent role in regional planning at the time. In engineering perspective, the choice of Tucurui was challenged by the project engineers, who favored a headwater dam above the large last dam project on the Tocantins. The engineers were sent and Tucurui (1984 first phase) became the first dam (Fig. 2) instead of the headwater dam Serra da Mesa (original name Sao Felix), completed in 1998 (Map 1c). Tucurui became a regional energy source first for Belem, which was freed of 'repressed demand' by 1984/5, then came the line to Sao Luis and its thermal plants were stilled. Then came the aluminum works at Barcarena and Sao Luis. With more turbines entering service, electricity dispatch to the northeast via Sobradinho Dam became a reality. More recently, Tucurui has been linked to Itaituba and Santarem via Altamira (230 kV line),

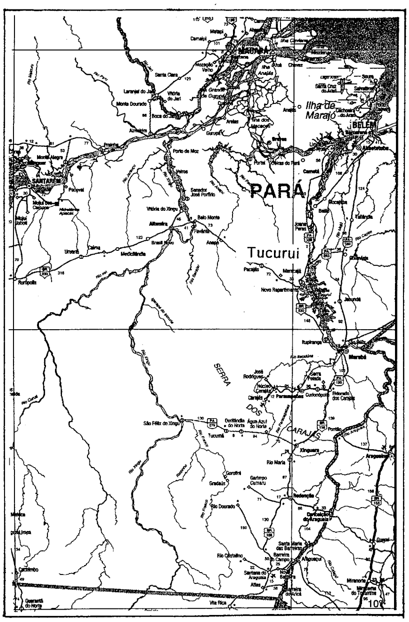
Fig. 2. Dam construction (May 1980) and river closure depend in part upon seasonal co-ordination to have an adequate cofferdam to protect the construction site. As the air photo illustrates the barrier was pushed from W to E on the river, with the powerhouse on the western side of the river. The construction side is ample in extent to facilitate service roads planning for cement portage and service equipment to the dam structure.

and in 1999 it became part of the national grid with a 500 kV line. The evolution of energy planning involves active fantasy, persistence, resilience, and much time.

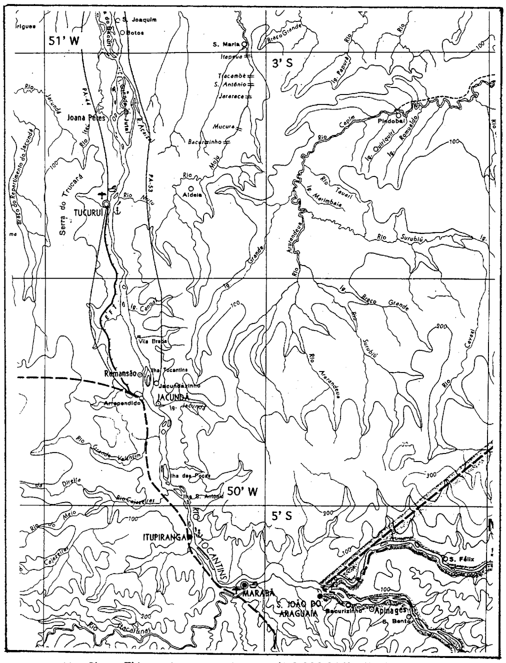
Lest it is assumed that local politics are all-passive, especially when there is no financial clout behind it, in Para that is not the case. There was agitation against the dam to a steady drumbeat. Brasilia, the government in the meantime, was changing the geopolitics of the region by referring to the province of Carajas (Map 2) (iron ore deposit—18×10^9 tons). The Tucurui project was included in the Carajas province [37]. And Carajas province would be another step to dismember Para State. Moreover, the railroad to bring the iron ore to the port linked Itaqui to Carajas instead of Belem. Maranhao State won the port battle. Para's resources left the state without contributing to its socio-economic growth. Thus, while the river was dammed and nature was changed, Para State viewed itself economically and politically used. Damming rivers thus has multiple dimensional characteristics. That draws attention and calls for analysis, namely the resources that leave the producing region fail to contribute to its social and economic benefits.

4.2.4. Changing nature—consequences

In creating an upstream and a downstream regime without any particulars is a notable change in a river's function as a master drainage channel. The location of the dam is significant in the total system, whether it is in the upper river segment, mid-river, or downstream portion. Aside from the possible numbers of affluents, which change total river volume, velocity, and sediment load, the dam location has varied impacts upon water management strategies. In the case of Tucurui Dam, it is at the northern edge of the Brazilian plateau, or the last effective dam site in the Tocantins Valley (Map 3a and b).



Map 3a Tucurui sphere of influence in lower Tocantins Valley(from Quatro Rhodas, (1997),BRASIL! 1:7,500,000)



Map 3b This semi-topographic map (1:2,000,000) affords an overview of the topography of the region. This is the boundary zone for the Brazilian shield and Amazonian lowland.

Map 3.

Serra da Mesa, the recently completed dam in the headwater region of the river, with a 54.4 km^3 reservoir, is the controlling dam in the Tocontins river system. Tucurui has no way to control any inflow into its reservoir. With Serra da Mesa in place, and numerous projects in various stages of construction on the Tocontins, it will become controlled by dams in the form of a staircase. This will change the nature of the Tocantins valley. It is instructive to point out that nature changed the course of the river to the west some three million years ago [14,15].

River scour is altered when clear water may deepen the riverbed as a consequence of abrasion, and at the same time sand deposition may be occurring some distance below the dam. Generalizations about the physical processes in river water movement and its physical work differs as a consequence of the geomorphic setting, such as mountainous topography versus tropical lowland geomorphology as exists in the Amazon basin or the Parana-La Plata drainage region. For the duration of the barrier the upstream-dam-stream differences will be notable and provide a quantitative record comparing pre-dam sediment transport and deposition, and dam water movement and downstream changes [16].

River basins in plains differ markedly from those in constricted physiography as the floodplain in plains spread horizontally while in constricted river courses a floodplain tends to be a pseudo floodplain in the form of a vertical terrace. Hence, sediments in the open floodplain sprawl while in narrow valleys they turn terrace-like.

Conversely, the disappearance of sandbars in plains below dams can disappear as the clear water can serve as ready carrier. Another form of channel alteration is 'slumping,' the gradual collapse of the river's edge into the watercourse. These often are silt deposits, often held in place by roots of grasses, bushes or trees, but water transport gradually removes the soil surrounding roots, plants tumble into the watercourse and the river wall caves-in. This has been observed along the Amazon in numerous segments, in Colombia, the Leticia area, Tefe, Brazil, Manaus, Brazil, Itacotiara, Breves Marajo Isl., Tucurui, Maraba on the Tocantinis, in Entre Rios near Diamante, and Parana to Santa Fe on the Parana. Hence, 'slumping' without dams is also a common process in channel change.

The Amazon as largest drainage channel without barrier below Pucalpa (Peru) illustrates its power as sediment carrier, and at Obidos it measures 1800 m in width and 90 m deep. Sioli observes 'Due to the strong current the Amazon moves a considerable bottom load of mostly fine to coarse sand… It does so in the form of giant ripples, or true dunes of up to 180 and even 600 m length and 6–8 or sometimes 12 m height' [17], p. 131.

The uniqueness of dams puts strains on generalizations, many of which tend to be too specific to have wider application. The identification of models that fit particular river systems appears indispensable for substantive riverbed morphologic analysis.

Before addressing the observed changes stemming from the construction of dams, it is appropriate to discuss the landscape, as it existed in the Tucurui region 18–15,000 years ago [18], p. 111–3. When the excavation for dam foundation reached its projected base level, a system of small channels was discovered, and these were traced to termites. The termites at that time have been identified with savanna vegetation association, which provides something of a reference point linking geomorphology and vegetation geography. Present day tropical forest in the region has an estimated age of about 4000 years. The discovery of these channels necessitated excavation of all base material that showed traces of termite channels, something that the geological fieldwork had no way of identifying. Dam construction was thus accompanied by unanticipated discoveries that could alter construction schedules and the level of scientific knowledge, as well as other environmental impacts after prolonged periods of seeming quiescence (Fig. 3) [23,30].

4.2.5. Forest clearance and dam system

Forest clearance varies in permanence with latitude and species diversity. In the tropical latitudes, between 23°30′ north and south, the vegetation association tends to be characterized by great diversity in species and rapid growth rates. High humidity rates and precipitation volumes, generally 1500 mm+, intensify regrowth rates of the local vegetation, and in Brazilian Amazonia these are termed 'caapoeira' (secondary growth), dominated by fast growing species plus some replacement species that effectively invade and compete for growth space difficult to penetrate in the previous vegetation association. Given these conditions, and considering that reservoirs are expected to be water basins clear of obstructions, an obstacle free reservoir is a seemingly obvious condition as part of the project-planning program.

Reality and preconception fail to coincide because of the growth dynamics of the local flora. In essence the volume removed in a prospective reservoir area in Amazonia will be

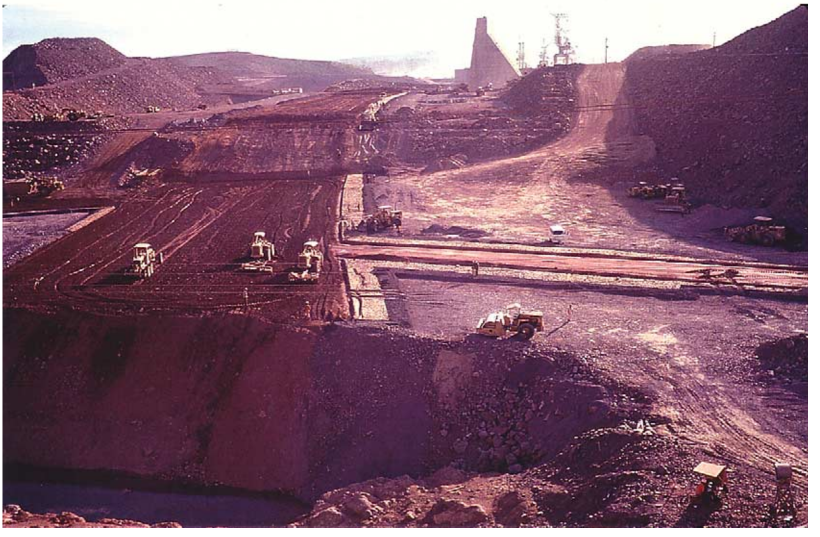


Fig. 3. A completed dam generally covers the width of its foundation, which measures in Tucurui about 370 m for the civil infrastructure, while the earth dam may reach a 500 m base. The picture illustrates the layering of clay and rock material, at the same time providing a visual assessment of the massiveness of the structures. This particular dam stores nearly 53 km^3 of water.

completely replaced in volume by secondary growth in as little as about six months. A reservoir that exceeds 200,000 ha or 2000 km^2 would require a mechanized labor force of an estimated 6670 workers to cut this area if an estimated three persons/ha per week are used for roughly 10 weeks. It is not only that the vegetation is cut, but also has to be removed out of the reservoir area, or alternatively buried to speed decomposition. The space and energy to achieve either solution add to the project base costs, as well as project chronogram. Fire could reduce biomass volume, but green vegetation takes a certain amount of time to turn burn-ready. The larger the area to be cleared and the denser the vegetation, the greater the volume to be processed will require that much more time.

A combination of variables, including the dominance of the natural growth characteristics of the tropical vegetation plus human limitations induce a powerless acceptance of nature's dominance. Instead of attempting reservoir clearance, project planners in the Amazon basin reconciled themselves to flooding the reservoir with most of the forest intact as is. A limited area above the dam is cleared of all vegetation to facilitate the control of floating biomass from entering penstock and spillway control gates. Booms above the dam are placed to stop loose logs and vegetation debris from reaching water intake suction tubes or spillway gates, and these are removed with regularity.

In Tucurui a local person of enterprising spirit developed a chainsaw that functions effectively in water. In essence this 'caboclo' (a resident of Brazilian Amazonia), without technological education, developed this machine so that the trees drowned by the reservoir waters could be cut at their respective base. A trained diver cuts, floated and brought the trees then to market. Lumber interests suddenly had access to a large supply of

high-quality lumber. It has to be noted that the interaction of reservoir waters with the chemicals in the wood acted as a preservative and created an active market for this lumber. Wood once inaccessible had become an export product.

4.2.6. Reservoir formation

Reservoir formation is conditioned by the seasonality of the precipitation regime in the river's watershed. Project engineers identify the time frame to time-river closing and anticipated period for the reservoir to reach its crest. Reservoir formation depends on stream flow volume and reservoir size. The latter makes for variable rates. Drought or excessive precipitation has to be allowed for. In the case of Tucurui, the 52.6 km^3 reservoir reached its optimal level within 6 weeks. Balbina required nearly a year to fill, and Kariba Dam on the Zambezi reached this condition only in the third year after dam closure. Reservoir filling has to be managed to avoid downstream displacement of the dam. To this end opening spillway gates open to different heights, creating alternate pressure points, diffusing pressure points of the released water against the civil structure significantly reducing dam displacement risks.

The rapid flooding of Tucurui resulted in the drowning of most of the reservoir area, about 248,000 ha, of a varied Amazonian vegetation mosaic. For the next several years the decomposing vegetation transformed the reservoir into a significantly polluted water body, with pronounced eutrophication notable some distance down-wind. In Tucurui most of the negative consequences were in the lake margins or segments that are distant from the dominant stream flow, drawn into the powerhouse and spillway. A relatively short residence of water in the reservoir accelerated the return to near normal water quality within about 6 years.

Once reservoir waters rise, the local fauna lost its habitat. Rescue activities [Cupira] were planned at considerable costs, but to expect these to achieve the wished for objective is unrealistic. Since the bulk of the affected fauna is most difficult to remove from such large areas, the effort has to be acknowledged, but its effectiveness is limited as the rescued and released animals survive in unfamiliar and contested territory in declining numbers. Even birds and reptiles fail to relocate as readily as is generally postulated. While fishing may favor fisherman, migratory species cannot spawn in their original spawning areas as the dam interdicts their course. Goulding et al. [19] report that long migrations of fish in the Amazon River system are common. In the Tucurui reservoir fishing in recent years has increased notably, and an estimated 6000 tons were marketed annually in the 1990s.

4.2.7. Changes in water quality

By 1991 the water quality in the Tucurui Reservoir had recovered to conditions that were prevalent in the Tocantins before September 1984, when the dam was closed. The local limnologists routinely collect water samples to assess water quality as a measure of dam and turbine protection. The cleaner the water the less damage especially to the civil infrastructure (the concrete and earth structure of the dam). The limnological laboratory performs one of the most important services for dam administrators, as reservoir water quality plays a significant part in dam maintenance expenditures.

4.2.8. Reservoir fishing

Dam managers are limited in their influence upon reservoir management beyond its water level regulation and electricity generation. People (in Brazil) who live in the reservoir area or in nearby communities pursue their interests without much concern for environment or project. Islands in the reservoir are deforested without attention to property rights. Sawmills locate at the reservoir's edge to minimize transport charges. Reservoir pollution marks their respective locations. Fishermen locate without any locational constraint and their presence is marked by styrofoam boxes on stilts to store their catch. Dam administrators have little if any influence over reservoir fishing activities. In a way they favor fish harvesting as a means to attract local good will. Dam administrators see active and productive fishing in the reservoir as a complementary function to energy production. On the other hand, they are vexed with the fishermen who harvest in front of the downstream powerhouse. It is here where the fish population is most plentiful as it feeds on the freshly turbine ground fish carried in the waters forced out of the powerhouse. A flotilla of six boats was observed below the powerhouse (July 1999), all of them tied to one another illustrating the fishermen's awareness of the risk factor and the potential to be drawn into powerful downstream currents where the water leaves the powerhouse. This daily presence illustrates dam management's relative socio-environmental and political impotence.

4.2.9. Transportation

River transportation was impossible above Tucurui because of cascading rapids. This condition was recognized in the 1930s and a railroad linking Jatobal with Tucurui was built (Map 3b). Tucurui below the dam has boat connections to Cameta and Belem. Tucurui Dam in its structure includes a lock to open an interior waterway onto the 'planalto', or the interior plateau, which is attracting more intensive farming, especially soybeans and upland rice. To further this conceptualization, another dam and lock have to be installed at the falls of Santa Isabel on the Araguaya River, tributary to the Tocantins.[3] The Santa Isabel falls effectively block Araguaya River navigation. Land transportation already benefits from Tucurui, which serves as bridge and major highway. The sparsely populated pre-reservoir area needed only a limited road system in the region; hence the reservoir flooded few active transportation linkages. A major road displacement was the segment of the Transamazon Highway farther to the west. Reservoirs influence the network of routes and affect the transportation flow patterns. These conditions of transportation pattern will become more notable as the population in the reservoir region increases and the transport network gains in density. At that time trans-reservoir transport lines may be opened.

[3] This Project has been approved as of late 2001, and will set in motion completion of the locks and canal at Tucurui. Once this project is completed, Belem as a port may not recognize itself in 20 years, 2022 or so. (International WATER, 2002, 5).

5. Dams in the public domain

Dams belong in the public domain because the water they control is to serve the public at large and not any particular interest group. Access to this resource should be universal without exception. Water should be available to all balanced uses with exception to polluting activities, which policy planners have to curb. Dams in the public domain have to be protected against detrimental uses. Pollution in hydro reservoirs would be damaging to generating turbines and gates in the spillway, and lock gates where these are in place as well as the civil infrastructure. For health and sanitary reasons dams should be surrounded by a 'cordon sanitaire' to curb erosion, pollution and spread of infectious diseases (malaria, schistosomiasis).

Most dams are built as barriers, not allowing sediments to pass downstream or fish upstream. This can be changed at additional project costs, but it has positive attributes in both instances. Dams in most cases are solid cement and earth barriers. Sluices under the spillway can be built to allow sub-dam water release instead over the lip of the spillway. This form of water release needs to be timed to coincide with volume of stream flow. This would allow sediment removal, which, in turn would increase reservoir storage volume. At the same time the hypolimnion would be removed and be replaced by fresh water. This would enhance reservoir water quality.

Upstream fish movement could be facilitated with the aid of elevator and directional lighting on the downstream side of the spillway section. The light would serve as directional beacon toward the elevator structure that would lift the fish into the reservoir where they could then resume their course to the spawning area in the stream. Neither of these two activities are year round, these are seasonal, hence their management costs could be made part of the energy and water use costs.

6. Society and water management—population increase, expanding energy and water demands

6.1. Damming the river

Society and water management foster change in the environment that alters pristine nature. Out of self-interest, society opts to impose upon untrammeled nature, geomorphology in this particular instance, with barriers-dams. Dams vary in purpose and magnitude, thus the range of impacts is proportional to need and water volume stored. Dams for hydroelectric projects in general are more massive than most other dams as the reservoirs are proportional to stream flow and water requirements of the installed turbines. Stream flow mean in the Tocantins, at Tucurui, Para, Brazil, averages about 11,200 m^3/s for the year, but its range is between 1700 and 68,400 m^3/s, which serves to illustrate volume volatility and the need for planning perspicacity. Observed and recorded stream flow data are not the defining parameters that spillway engineers use, but their projections include the one in 1000 year stream flow maximum. At Tucurui the spillway can pass 110,000 m^3/s, which serves to illustrate the necessary hydrologic projection that guides spillway design and magnitude. Furthermore, with 23 turbines in place when completed by

2006/7, an additional 13,340 m^3/s can transit the powerhouse, or the Tocantins could carry in excess of 123,000 m^3/s through the dam. No river on the North American continent reaches even 50,000 m^3/s [20], p. 38–65. At Vicksburg, MS, the Mississippi's mean value is 17,700 m^3/s, in 1979 its maximum reached 43,800 m^3/s in April, and declined to a minimum of 4760 m^3/s in October of 1976. Dam structures thus incorporate features that may never be needed in reality, but have to be included for extreme possibilities.

Proper project planning has to include evaporation rates for large open water bodies. In the case of the Aswan High Dam, 14–15 km^3/year are lost to evaporation, or about 440 m^3/s. At Sobradinho, Sao Fransisco, Brazil the river in the air averages 210 m^3/s throughout the year.

Water use effectiveness varies with height of dams and turbine type installed. The Pelton turbine is used in dams generally above 150 m high. The two turbines in widest use are the Kaplan (similar in structure to the propeller screw used in ships), for generally lower dams, up to about 50 m, and the Francis Turbine for the dams of 45 m to above 250 m of dam height. At Tucurui a 57 m drop, a 350 MW Francis turbine needs about 585 m^3/s, at Jupia, Parana River, Brazil, a 100 MW Kaplan requires 400 m^3/s. This comparison affords an idea of what influences reservoir size planning associated with electricity generation. Water management is foremost a practice of balancing available stream flow volume with societal energy needs and other requirements. Distant population concentrations increasingly influence remote energy production. Societies' growing dependence upon advancing technology brings with it modifications in river regimes and their geomorphology as well.

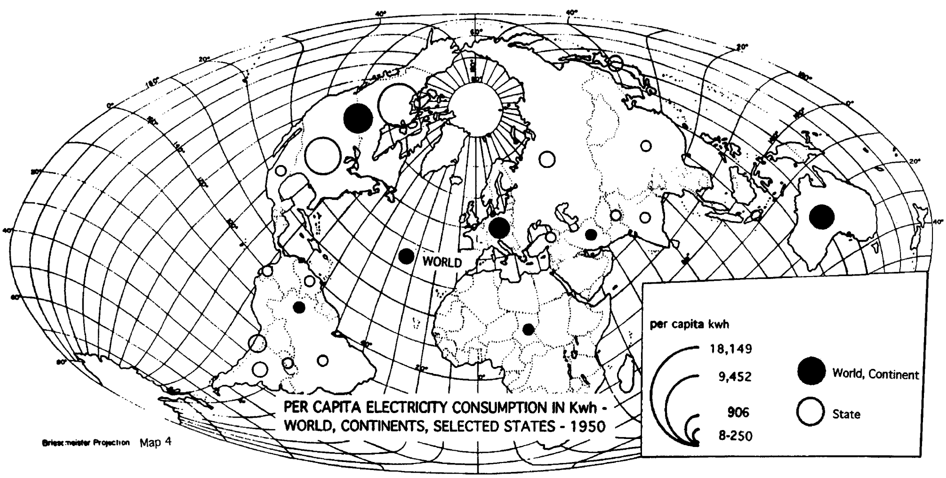
Population increases and growing energy demands exert pressures upon the environment that shape energy policy and planning most everywhere. Planning depends upon data, and where the culture of data gathering is unknown or novel, or where the data availability is too recent it fails to afford confidence for its planning uses. Furthermore, where population increases are high in general, energy needs may be correspondingly strong, but the general data reliability tends to be fragile. Conversely, societies with advanced technologies turn to hydroelectric energy to curb air pollution in response to growing electricity consumption. The stress put upon the environment by a combination of vectors points to the need for long-range electricity project planning that includes conservation of energy and more energy efficient equipment. Concurrent with expanding energy demands, planners have to provide for advancing water demand and consumption. In much of the world where urbanization shows high annual rates of change, notably large states such as China, India, Indonesia, and Nigeria, electricity consumption and water consumption in per capita values afford the resource planners few if any options. All of this moves water management onto and up-on water policy agendas of most societies with long-term adverse consequences for local geomorphologies.[4]

[4] Hydroelectricity is the theme, but other water systems need to be considered in the context to retain perspective for the social vector as well as the agricultural systems. Irrigation is a leading consumer of water, about 70% of all water worldwide. Alternative energy sources attract much attention and provide little in actuality. For alternative energy to materialize, a 30–50 year time frame has to be allowed.

6.2. Rationality

Damming a river is a technical process based upon geologic field evaluation of the dam site and civil engineering analysis of required civil infrastructure and material requirements. Dams are generally built to serve specific social-economic needs. The larger the project the greater the involvement of varied interest groups and the larger the political arena in which contending interests have to reconcile actual and perceived differences. As dams tend to have an extended service period, social, economic and environmental planning has to be mounted on a large and flexible canvass. Moreover, the environmental impact assessment has to be detailed to afford long-term projection to measure the impact and reconcile it with the benefits for several decades into the future. Here economic benefit analysis should serve to project productivity and returns, as well the anticipated service period of the dam. Dam productivity can be assessed in economic terms, in social context, and in environmental setting. Dams inherently have a local service shed, but larger projects tend to have regional impacts, and very large projects, of 3000 MW + contribute to a country's distribution grid.

Environmental considerations, including constraints, have acquired increased significance within the 1970–2000 period. Project viability has to meet increasingly stringent qualifications previously addressed in a more liberal spirit, and/or possibly a less transparent evaluation process. To this can be added the cumulative experience of about 110 years of hydroelectric dam construction, and their respective productivity and environmental impacts. Hence, it is rational to consider fully how to optimize dam performance. Dams' sites are unique in site characteristics; it is therefore unwise to expect uniformity in environmental conditions, which makes uniform setting requirements impractical in application. Site uniqueness makes cost projection per installed kiloWatts unrealistic, even though such consideration has its appeal. Aside from the physical

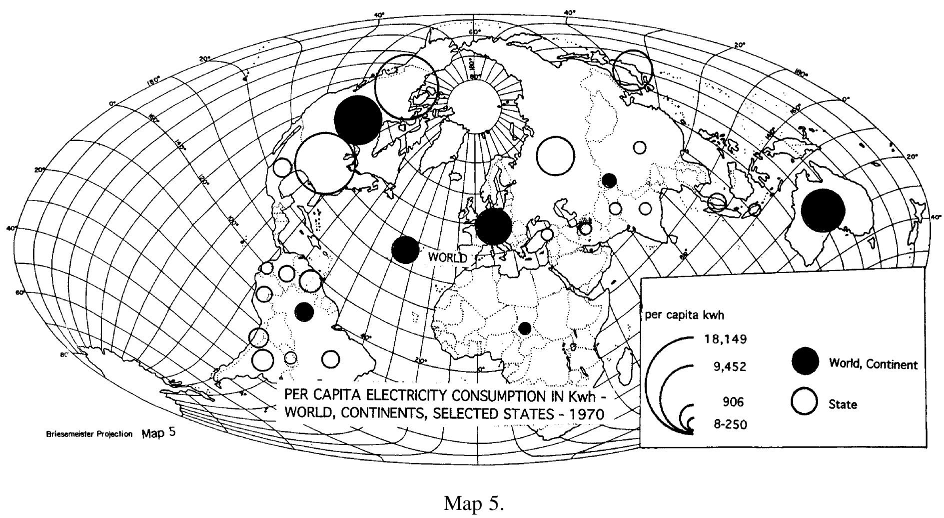


Map 4.

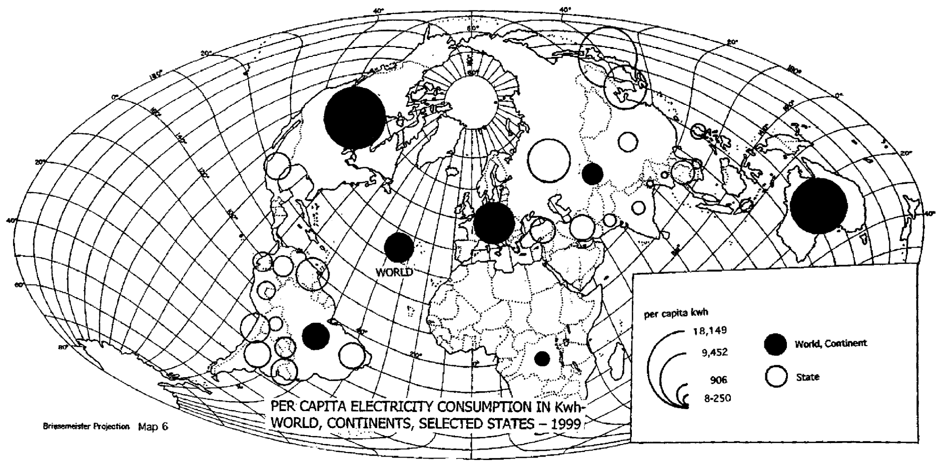
characteristics of a hydroelectric project site and the watershed where it is to be placed, the local demographic profile in its multiple dimensions has to be assessed environmentally as well as in other contexts.

Change in living standards and urbanization tend to generate increased per capita energy consumption (Maps 4–6). Comparing Asia and South America points to parallelism in per capita consumption increases for the period mapped. This condition tends to be punctuated by 'repressed demand', or the energy consumers have to do with considerably less electricity than they can consume. To overcome this shortfall of energy generation the market seeks to meet the demand, either via private terms or via government-financed sub-ministries. Within the last 100 years electricity has achieved such dominance in daily life that shortfalls have become politically charged issues. Once access to electricity is easy, the demand to date instead of stabilizing continues to advance (Maps 4–6). This opens a window on energy conservation that in the rush to meet increased demands is generally overlooked.

It is useful to include ideas on how to produce and use electricity more rationally. Conservation is the first item on such a list, as it is environmentally perfect, and economically cost attractive. Conservation's worst enemy is convenience, but negligence must be considered a significant variant as well. A second approach to energy conservation is technical, as all the electricity consuming mechanisms could function with greatly reduced 'wattage'. Light bulbs may serve as example. Incandescent bulbs of 100 W can be replaced with fluorescent bulbs of 25 W emitting the same amount of light. In machinery, similar economies of electricity can be achieved, which have far-reaching consequences in terms of economy, environment, and equipment lifespan. A third way to achieve electricity conservation could be by means of variable utility rate structures. Telephone firms use varied tariffs for different times of the day for phone users; electricity rates could be period-priced in a similar way to achieve conservation and better time distribution of electricity consumption. Aside from inducing conservation, it would mean more balanced use of installed available electricity throughout the day.



Map 5.



Map 6.

A fourth option is to identify the kiloWatts output per flooded hectare to assure economic-environmental project viability. Engineers project annual hydroelectric output on average of 57% of installed nameplate capacity[5]. If the rate is set for purposes of illustration only at \$0.02/kW h, and the reservoir area is known well ahead of its actual formation, the return per hectare and number of kW h can be readily identified. With this information, it becomes possible to identify economically viable projects[6]. If the \$0.02/kW h is used on an annual basis at 57% of operating capacity, 1 kW h/ha per year yields about \$100. Agricultural land in wheat or corn could out-produce \$100, but when the \$1000/h level is reached, wheat and corn are out of contention. Only rice or more costly crops yield a comparable or higher return per hectare. Projects that have a potential to generate 10 kW h/ha or less should be considered only under exceptional conditions. A desirable base value would be 15 kW h/h per year, as this yields \$1500/h per year or $(15\times 24\times 365\times 0.02\times 0.57=\$1497.96)$. This would be economically rational and serve as an environmental constraint. At Pangue on the Bio Bio River, Chile, the reservoir is at most 540 ha; each ha produces nearly \$90, 000 in electricity per year. The Xingo project on the Sao Fransisco River, Brazil possibly out-performs Pangue. Exceptions do not make rules; they serve instead to identify the potential range of the subject considered.

7. Change in project scales

Change in project scales is foremost a response to demographic pressure and a consequence of gaining technological sophistication as well as the application of

[5] Project planners differ in estimating projected % of electricity generation. Most opt for a 50% electricity production of installed capacity. The more dams are on one river, the higher the potential productivity as the downstream dams generally reach 60% marks or better.

[6] Projects no longer are built without opposition, hence one has to anticipate objections and accommodate these as appropriate and viable within the larger scheme of societal change.

economy of scale. Without any doubt this topic can be treated at monograph length; here it is used as a benchmark to acknowledge the increasing magnitude of projects and the consequences for changes in riverine systems and environments. Project location relative to consuming region initially was defined by the available transmission technology. Hoover dam dating to 1936 advanced project separation from consuming center. Tucurui dam was planned as a multi-regional service unit to send electricity to Sobradinho 1650 km (about 1040 miles) in Northern Bahia for distribution of electricity to Fortaleza, Recife and Salvador, to service Eastern Amazonia especially Carajas mining and eventually be tied into the national power grid [31]. Tucurui by 2002 and after will increase its installed capacity to 8320 MW. While 'small is beautiful', the Schumacher [33] dictum, which has much appeal, it fails to meet the voracious demand for-ever more electricity. And this drives dams as Tucurui, Itaipu, Three Gorges, Guri, or Grand Coulee to bridge the energy gap that energy planners seek to close.

Projects on the drawing boards or in construction tend to be generally large, 500 MW and larger. In China seven projects in construction range in size from 1200 to 18,200 MW, with 13 more planned ranging in generating capacity from 1200 to 14,400 MW (HYDROPOWER OF DAMS-2000 WORLD ATLAS, 2000, 95). Iran has several dams in construction, five of which range from 1000 to 3000 MW, and two of 400 and 640 MW (HYDROPOWER OF DAMS-2000 WORLD ATLAS, 2000, 101). Japan has six plants in construction, four range from 1200 to 2700 MW, and two units under 500 MW (HYDROPOWER OF DAMS-2000 WORLD ATLAS, 2000, 105). In India seventeen projects are in varied phases of completion, 4 are 1000 MW or larger, and 13 range between 300 MW and 900 of installed potential (HYDROPOWER OF DAMS-2000 WORLD ATLAS, 2000, 98). Turkey has 37 power plants in various phases of construction and 344 are planned (HYDROPOWER OF DAMS-2000 WORLD ATLAS, 2000, 132) [24]. The magnitude of the projects and great numbers point to their functions as 'energy bridge' as the building states consider the alternatives as unattractive to meet socio-economic needs for the foreseeable future. What is not explicit in these numbers is the attendant environmental planning required to minimize environmental stress [21]. Furthermore, in populous China most any dam can be expected to be accompanied by substantial population relocations.

Dam construction and reservoir formation brings with it a re-ordering of settlement, land use, and transportation patterns. How this spatial re-organization unfolds is the product of particular political organizations and particular cultural systems. While the processes tend to be uniform physically, and the social and cultural dislocations are similar in character, the responses and expectations of the involved parties have to be viewed in cultural context for their individuality, and the circumstances in which these take place. It is the magnitude of the projects that draw attention. Moreover, while focus is on these changes, the associated changes that bring about these projects are at most peripherally considered. This generally involves people, notably those with limited income. The margins for options are dismally limited.

Resort to large projects reflects the population pressures that these projects are the answer to. Add to this that as societies become more urban, they become more water and energy dependent. And as these populations become more educated, they require more

energy to function economically and culturally. Economic change raises expectations and these are in good part environment dependent. Alternative energy sources available are too small in magnitude and too time consuming to meet the immediate energy needs. In Brazil it was 'repressed demand', in the United States, particularly in California, 'deregulation' that bring into daily light the lack of energy. And while the focus here is on waterpower, water for water-sake as resource calls for even more concern and attention, than hydropower.

8. Damming the river: changing floodplain settlement

Few if any river floodplains are without human settlements. Variation in floodplain population density varies for reasons of demography, culture, property rights, resource management, land quality, and land use practices and policies. River closing with a dam and reservoir formation imposes relocating upon the floodplain settlements. The re-settlement process is burdened with terminating a spontaneous-tradition-bound attachment to specific settlement sites, which commonly include important cultural markers such as buildings, homes, fields, cemeteries, and communal facilities. The prospect of an uncertain future in an unfamiliar place further intensifies identification with the pre-flooded home area, and foster resistance to relocation. In the past project planners relegated relocation planning to low priority status. For a variety of reasons past neglect has been replaced with increasingly fuller attention to those about to lose their homes and land. Relocation costs became part of project costs, and these can rise significantly. Even in areas sparsely peopled, the news of project installation draws occupants into the-to-be-flooded area as squatters to receive compensations for their residential sites.

Resettlement has to be considered a wrenching tribulation for those who have to vacate hearth and field. Even under financially favorable conditions, forced spatial relocation encumbers the resettled with sentiment of uncertainty and loss of long-term social ties. The Brazilian power-producing firms seek resolutions of the settlement issue on the generous side. At Salto Grande, Uruguay River, a cousin had to surrender her home in Federacion, E.R., Argentina, in 1978 to the forming reservoir; this after 32 years in that home. At Tucurui, Brazil, the project negotiators may have been well intentioned, but the resettled got little beyond new houses. Resettlement tends to be mechanistic in addressing a psycho-economic problem that defies formula solutions. It is the human component that evokes the dominant concern of resettlement schemes in upstream settlement clusters. Resettlements in project areas in China and India pose the greatest challenges because these areas have population densities in many parts in excess of 250 persons/km^2.

Relocation planning in project areas has to include project costs, future energy costs (excluding specific industries) and the region's economic health. The extent to which resettlement is planned varies significantly, provision for adoption by the resettled generally is short on generosity. In South America for the most part the resettled can stay in proximity to the original settlement area. In Asia this is far more difficult, notably in the Yangtzee Valley-Three Gorges project. Here the given number to be resettled is

1,300,000, but by the time the reservoir is filled this number could swell significantly.[7] Policy makers and planners consider long-term perspectives which involve their infrastructure formation planning with an air of immediate insensitivity while their gaze has a 20–50 year horizon.

9. To dam or not to dam: hydroprojects as 'energy bridge'

Dam builders lack the option of Shakespeare's *Hamlet* 'to be or not to be'; policy makers send them to build. Even if engineers question the viability, the location or technical characteristics of a hydro project, the policy makers decide and prevail. Policy makers have to be future oriented; hence any immediate dislocation or discomfort carries little weight in their decision-making. Projects of magnitude tend to include corrupt practices, notably in contracts with large building firms and component suppliers (the United States interstate highway system included a 10% allocation for contract elasticity). Hydro projects are evaluated on the basis of the cost per installed kW. Project viability then depends upon economy of scale to reduce construction costs to the lowest kW cost to allow early repayment of project costs. Dam costs tend to be substantial and loom larger because the time during which there are only expenditures and absolutely no income. Time frames vary with project magnitude, but larger dams absorb investments over a 15 year + span during which surveys, inventories, contracts, and wages have to be paid out without any income. When the first turbine comes on line in a multi-turbine project, the project is only complete when the last turbine is turning. And then, if there are no deleterious energy contracts, repayment can start and a low cost or kW dam could pay for itself in seven to ten years.

Dams serve as 'energy bridge' for many states as these lack substantial domestic energy sources to meet domestic energy demand. Dam building is done sparingly because of the high-cost, initial capital requirements. States like Turkey, Brazil, and China have large hydro-potential, but very limited oil and gas resources. Policy logic shapes the decision-making process to use first the lowest cost and more accessible energy sources. In most cases water is a domestic resource and as such no fluctuating world commodity prices tend to influence its availability or use. Domestic energy planners implicitly are encouraged to foster foreign exchange conservation and conversely to promote domestic energy options-hydroelectric in this case, namely the 'hydroelectric bridge'.

Environmental awareness fosters more comprehensive consideration of hydroelectric projects and their impact upon the environment. Two aspects of land loss to reservoir space draw attention. First the physical variables of flora and fauna create changes in the environmental associations in the impacted areas. Second, the displacement of people and cultural sites in the landscape introduces locally social tensions that can command costly

[7] In West Germany, the mining of brown coal involves the removal of towns, cemeteries, and industries. The brown coal goes into thermal power plants for electricity generation: Here the resettled relocate to planned communities, and the agricultural land is restored once the coal is depleted. The 'common welfare' has varied parameters.

mitigation and often project modification. Dam development is increasingly approached with constraint and more comprehensive planning. The professional journals such as Hydropower and Dams, International Water Power and Dam Construction, and World Bank Studies (Butcher, op.cit), address environmental conservation, social impacts, project viability, and project acceptability, to cite key issues. Hydroelectric project managers are environment sensitive to protect the project against negative variables, such as debris, water pollution, cavitation, excessive sedimentation and over fishing. All of these precautions are generally used to protect projects, but there are few constraints imposed upon the energy-demanding public. Annual energy demand growth rates of 4–5% are quite common. It is the unregulated energy demand that contributes to the unabated, pressure to build more large hydroelectric projects. Another way to corroborate this is by comparing per capita electricity consumption rates for 50 years to assess these values for selected states in the world. Maps 4–6 show the change over time spatially, the select data in Table 1 illustrates the per capita increases for the countries shown. This process is near universal. Dam building is a response to electricity consumption that exceeds the projection of previous energy planners (Consider merely in the United States that computer screens that are continuously on, the two and three telephone household, and suddenly brownouts become headline grist for newspapers and television). Dams in fossil-fuel poor states become attractive energy alternatives to foreign exchange consuming imports of fossil fuels.

Just as environmental awareness and protection have become commonplace, so have adequate energy availability turned indispensable for viable economies. This places the locally most accessible energy source very high on energy policy planners' agendas. Technological change is energy driven, which enhances specific energy sources' attractiveness for utilization. To dam a river turns into a viable energy option that long-term energy policy makers will evaluate and use after alternative option evaluation. Brazil was taken by surprise with the 1973 steep rise in petroleum costs and its energy planning went into high gear turning to hydropower to idle petroleum-using thermal–electric plants as quickly as this could be achieved. Dam building is best considered as a 'bridge' to a 'metamorphing' energy economy. Dam construction comes with baggage that most governments would be most relieved to travel without. Reality trumps environmental rationality. This consideration applies to far more resource and land use practices than generally critically assessed.

Electricity generation is powered by either non-renewable energy sources such as fossil fuels, uranium, or renewable-energy prevalently water, but also wind power. The focus here is on the hydropower sector. The United States dam population reported by Gleick totals 49,251 units, based on 1977 data [10]. Among this number a few categories deserve special attention. Nearly 34% of the dams serve recreational ends, irrigation nearly 13% [22], and hydroelectric projects nearly 3%. Water storage volume for flood control comes to 360 km^3, or 16.7% dominate the distribution when mass is considered. Dams then serve a multitude of environmental manipulations, changing nature in multiple ways to serve organized societies. If dams are removed and ground water sources are tapped, what will be the impact and its consequences? Societies have to learn to do more with less to protect the environment.

Table 1
Electricity consumption: KWh/p/y Asia and South America 1950–2000

	1950		1960		1970		1980		1990		2000		1950–2000
	KWh/p/y	%Δ	KWh/p/y	%Δ	KWh/p/y	%Δ	KWh/p/y	%Δ	KWh/p/y	%Δ	KWh/p/y	%Δ	%Δ
World	382		763	100	1347	77	1601	19	22.07	39	2475	12	548
Asia	41		122	198	279	129	510	83	817	60	1288	58	3041
Bangladesh							30		70	133	113	61	277
China	8		90	1025	142	58	305	115	546	79	1057	93	13113
Cambodia			11		19	73	16	−16	8	−50	17	112	918
India	20		47	135	111	136	173	56	336	94	543	62	2615
Indonesia	10		15	50	19	27	46	142	240	422	473	97	4630
Iran					238		442	86	1026	132	1827	78	668
Iraq	23		124	439	294	137	606	106	1541	154	1330	−14	5683
Japan	541		1239	129	3509	183	4949	41	6944	40	8603	24	1490
N. Korea			868		1188	37	1956	65	2457	26	1474	−40	70
S. Korea	21		70	243	307	330	1049	249	2775	165	6243	125	29629
Laos			6		28	367	56	100	88	57	95	8	1483
Malaysa					326		734	125	1379	87	2977	116	813
Mongolia	28		114	1307	439	285	1194	172	1717	44	1302	−24	4550
Myanmar			20		22	10	38	73	62	63	106	71	430
Nepal	1		1		7	600	17	143	40	135	67	68	6600
Pakistan	5		22	240	60	173	175	192	358	105	478	33	9460
Philippines	36		98	172	231	136	373	62	422	13	593	40	1547
Saudi Arabia					185		2049	1008	3354	64	5908	76	3094
Sri Lanka	11		31	182	65	110	113	74	183	62	354	93	3118
Syria	46		81	76	151	46	428	183	846	98	1386	64	2913
Thailand	4		22	450	124	464	342	176	840	146	1674	99	41750
Turkey	38		102	168	244	139	584	139	1017	74	1803	77	4645
Vietnam			28		50	79	71	42	131	85	342	161	1121
USSR/Russia	507		1363	169	3043	123	4802	58	5856	22	5937	1	1071
Africa	66		128	94	244	91	321	32	486	51	524	8	694
Europe	773		1607	108	3077	92	4551	48	5710	26	5168	−9	569
Oceania	1019		1960	92	3620	85	5322	47	10600	97	8362	−21	721

North America	2061	3643	77	5934	39	7611	29	8658	14	10388	26	404
Belize	15	66	340	192	191	372	94	561	51	648	15	4220
Costa Rica	210	354	69	594	68	977	65	1251	28	1889	51	800
Cuba	205	432	111	570	32	1017	78	1531	51	1343	−12	821
Dom. Rep		109		234	115	494	111	743	50	1139	53	945
EI Salvador	34	97	185	187	93	322	72	438	73	676	54	1888
Guatemala	27	71	163	142	100	223	57	253	14	469	85	1637
Haiti	6	24	300	26	8	54	108	73	35	80	9	1233
Honduras	33	47	42	119	153	250	110	247	1	617	150	1770
Jamaica	118	312	164	825	164	1035	26	1112	7	2518	126	2034
Mexico	166	304	83	564	86	972	72	1367	41	2368	73	1327
Nicaragua	73	125	42	305	144	380	25	320	−16	474	48	549
Panama	122	148	21	565	282	1255	122	1247	1	1734	39	1321
USA	2571	4698	83	8008	71	10459	31	12170	16	14684	21	471
South America	167	349	109	564	62	1131	101	1504	33	2055	37	1131
Argentina	301	507	68	906	79	1406	55	1601	14	2437	52	710
Boliva	82	130	59	182	40	281	54	268	−5	475	77	479
Brazil	154	315	105	474	51	1149	142	1643	43	2345	43	1423
Chile	483	605	33	806	33	1058	31	1395	32	2713	94	462
Colombia		241		416	73	890	114	1098	24	1039	−5	331
Ecuador	27	88	226	159	81	386	143	598	55	839	40	3007
French Guiana		129		1146	788	1697	48	3418	101	2758	−19	2038
Guyana	83	162	95	456	182	484	6	276	−43	1158	320	1295
Paraguay	35	54	54	95	76	268	182	430	60	1116	160	3086
Peru		267		419	57	567	35	641	13	776	21	191
Suriname	163	272	67	3554	1207	4574	29	3199	−30	3780	18	2219
Uruguay	275	490	78	793	62	1579	99	1953	24	2390	22	770
Venezuela	237	616	160	1159	88	2298	98	3091	36	3525	14	1387

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10. Changing nature—difficult choices

Dam construction is a socially economically conditioned response to identified community needs. As such dam construction has a history that spans nearly 5000 years. Hydroelectric dams are comparatively recent in this chronology and are markers in the trajectory of the history of technology. Possibly the first functioning hydroelectric unit entered service at Appleton, WI in 1882 [3]. Like with most firsts, this dam was designed to meet limited energy needs for which virtually no water storage was required. No reservoir of consequence formed behind the dam. It was a run-of-the-river plant, without a notable barrier, a dam. Increased dependence upon electricity created a growing dependence upon regularity in supply and in the case of hydroelectric dams, availability of water for dependable electricity output. Regulation of the electricity supply was achieved when the water supply in an open river was brought under control with the building of a dam. Turbine performance is contingent upon a 'regulated' water intake. Reservoir formation answered to that requirement. Rising electricity demand fostered technological change, which over time led to increasing distances between electricity source and electricity consumers bridged with ever improving transmission systems. In the past transmission distances were reckoned in meters, advancing technology increasingly reduced the distance constraint on electricity transmission and with that came a larger range of dam site options. Remote sites previously beyond reach became part of a state's hydroelectrical potential, and in time part of the country's energy plan. Whereas in the early history of hydroelectric projects output was measured in hp or kW, in the 100s or low 1000s, since the 1960s/70s, the reference point is 500 MW and up. Small hydro continues to be built to serve small load consuming centers. At this time the largest project on line is Itaipu-Bi-Nacional with 12,600 MW, slated to reach 14,000 MW, and Three Gorges dam in construction for 18,200 MW, affording perspective on the leap from hp or kW in very small numbers to million values. What is being recorded and observed is the changing scale of demand and need for energy.

Dams are not being built by Pharoes to confirm their immortality or as monuments to contemporary political potentates. Dams have become very large, very costly and very inconvenient for those who 'resided' in their immediate future reservoir basin. Dam construction happens after protracted studies, local and environmental objections, political positioning and in anticipation of electricity demand. The path to the realization of such project generally spans 15–25 years and it is costly in every respect. Capital requirements make these projects vulnerable to a large phalanx of constraints in the political, economic, social and environmental spheres, to cite the more prominent considerations. There is a plethora of opponents to hydroelectric projects, and their objections are understandable; however, they neglect to inform about viable energy alternatives with which energy planners could respond to surging electricity demand. The report by the World Commission on Dams is an example of criticism that is unbalanced and lacking in workable recommendations [29,34]. The IHA (International Hydropower Association) explains this in detail in a letter to president Wolfensohn of the World Bank ('Response', 7 Feb. 2001: see also Anon, International, Jan. 2001, 18–19, 21) [28]. Governments, in spite of these reservations, especially with advancing transparency, turn to dam construction because of the limitations of the alternatives. In the assessment of hydroelectric projects,

dam critics lose track of actuality as more, many more, dams are being built for functions other than hydropower.

If one considers the bulk of literature on alternative energy sources, and compares that with the literature on hydropower, the optimism of the new path literature suggests that the world could be adequately supplied with electricity. That it is not, is a reflection upon the difficult path from familiar to novel energy sources. The quest for alternative energy sources dates especially to 1973 when petroleum prices left their low price moorings and all and any domestic energy source appreciated in absolute value. There have been inventions that have found acceptance. Among these eolian and geothermal energy as renewables have found favor. Their contributions to country energy matrixes remain modest while electricity demand surges. This leads back to large hydro-projects, which deliver large bundles of energy to operate on average at 57% of installed nameplate capacity throughout the year. That explains in good part the continued acceptance and dependence upon hydroelectricity. Hydroelectric units serve the transition to a metamorphing energy future, without a fixed time frame. Most dams serve easily 100 + years. Itaipu is projected to serve for over 200 years.

Hydroelectric projects tend to be considered in an unfavorable context-as-enemy. These projects are generally very large, hence the large units are government owned and operated, or these are the people's property. They were built in most instances to serve the public's needs. Hoover Dam, TVA, Grand Coulee in the United States became foci for regional economic change. While the initial costs of these projects are comparatively enormous, their long-term return is impressive. It is this latter aspect that is generally under-reported or not considered. It is precisely this aspect that is the motor that drives the acceptance of dams as key energy sources. The assessment of the environmental costs has to be included in any project analysis, and to be added to the energy rates charged. All of this points to the need to create a hydropower technology that is river-tailored. Small streams would have turbines that can operate with minimal conditions, and very large rivers have large turbines, all operating in a floating position without a dam. The question of regularity and the amount of energy that can be dispatched is an engineering problem that may be within reach.

Dam critics like to refer to cost overruns and under performance of projects. That there are dams that 'should not have been built' needs no long discussion, Balbina in Brazil, Brokopondo in Suriname, and Akasombo in Ghana serve to make the point. The problems generally identified with dams relate to the policy decision-makers and politicians. Schedule changes, corruption, and local favors, all these influence dam-completion schedules and project costs. It is the project that pays the bills; it is people that seek advantages. Dams can be productive in multiple ways, and one in particular contributes to it becoming part of the local where it is sited, namely paying a royalty based on the electricity dispatched from the local community where it is generated.

Dams are geomorphologically unacceptable. Dams are socially unavoidable. This is simple, it is obvious, and a way has to be sought to harmonize the natural with the social to protect the interest of each and achieve viable compatibility. The 'choices' are difficult and not reachable with mere nice words or sentiments. The environment 'has to be protected'; humanity continues to seek a better standard of life. While the 'choices' may be difficult, the obvious first one is 'energy conservation', the second is the application of

'energy conserving technology', third, dams should have a minimum kW/ha output, or any project that would produce under 10 kW/ha would not be freed for construction; this would significantly reduce reservoir areas, notably shallow reservoirs, and reduce evaporation water losses; the fourth is to develop 'energy quotas' for: A. daily uses, and B. an annual energy allowance. Beyond that, lie quota systems for significantly higher energy rates. It is persuasion through the purse, not administrative dictates to foster improved energy balances and promote better environmental protection.

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